Improved PV System Reliability Results from Surge Evaluations at Sandia National Laboratories

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Abstract

Electrical surges on ac and dc inverter power wiring and diagnostic cables have the potential to shorten the lifetime of power electronics. These surges may be caused by either nearby lightning or capacitor switching transients. This paper contains a description of ongoing surge evaluations of PV power electronics and surge mitigation hardware at Sandia.

1. General Introduction

Direct lightning strikes are expected to cause extensive damage to PV equipment and are not the subject of this effort. However, electronics equipment can be hardened to the damaging effects of nearby lightning. Nearby lightning couples to wires through magnetic and electrical fields that are radiated and conducted from the area of a lightning strike. Surges due to nearby lightning are much more frequent than those from direct lightning strikes. Electrical surges that result from load transients, commutation notching, fault clearing, capacitor switching, and system faults can also adversely effect grid tied inverters.

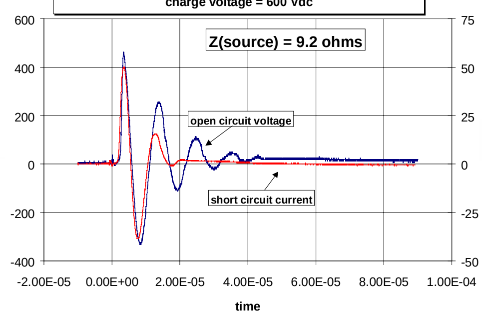
At the request of inverter manufacturers, Sandia National Laboratories (SNL) has recently begun evaluating the response of PV inverters to such nearby surges. At this time most PV inverters do not have surge protection and there is evidence that electrical surges are reducing inverter reliability. Failures, in turn, result in increased repair cost and higher inverter cost. Additionally, the continued ability to avoid islanding after such surges is a utility requirement. Because of reports of field failures due to nearby lightning strikes, this effort is expected to improve the reliability of PV hardware as well as remove barriers to installation on US electric utility lines.

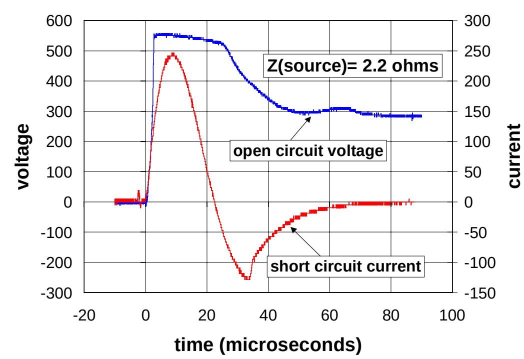
IEEE C62.41-1991 defines the source and frequency of potentially damaging surges and defines the standard surge testing waveforms. IEEE C62.45-1992 discusses the low-voltage equipment test conditions and test methodology in detail. It defines a location category C that includes inverters that are located outside and specifies test pulses with up to 10-kV charge voltages. Location category B (pulses up to 6 kV) includes the building service entrance and has been selected by SNL as the most appropriate location category for typical PV inverter evaluations. Location category B specifies test pulses with up to 6-kV charge voltages. The selection of 6 kV as a peak voltage for indoor systems results from the fact that conductors for indoor systems are spaced such that voltages greater than 6 kV will generally arc. Similarly the value of 10 kV for category C results from dimensions in outdoor wiring that would generally arc. Two pulses are described in the IEEE documents: (1) a .5 µs rise time -100 kHz ring wave (Figure 1), and (2) a 1.2 x 50 µs (rise time x pulse width) –8 x 20 µs combination wave (Figure 2). The combination waveform is a 1.2 x 50 µs voltage pulse into an open circuit and an 8 x 20 µs current pulse into a short circuit. The pulse shape and the charge voltage applied to capacitors inside the surge generator determine the energy in the applied pulse. Charge voltages for location B are variable up to 6 kV. Surviving these pulses does not ensure that an inverter would survive nearby lightning. In fact, the levels of the pulse are negotiable by the parties involved in the evaluations. Surviving the pulses does confirm a certain desirable level of hardening of the inverter.

2. Laboratory Test Capability

A Velonex Model 587 high voltage surge generator and a Velonex V-2734 isolation unit are used in the SNL evaluations. An additional 1.2 x 50 µs waveform is available to pulse high impedance circuits. If, as is typical, the inverter inputs have low impedance then the 8 x 20 µs pulse, defined for a short circuit, is the more severe stress. The respective source impedance of the three SNL waveforms are 9.2, 215, and 2.2 ohms.

Figure 1: Velonex 100kHz ringing pulse Voc & Iss
charge voltage = 600 Vdc





Test Philosophy: The test philosophy includes the following elements:

a. Incremental Application of Stress. Pulses result from the discharge of a surge generator capacitor through the impedance presented by the inverter. Thus the actual output voltage may differ significantly from the capacitor charge voltage. The initial charge voltage is chosen as 500 volts. Subsequently, to determine the level of hardness of the equipment under test (EUT), the charge voltage is incremented in steps of 1000 Vdc from 1 to 6 kV. As the charge voltage is increased it is probable that a protecting device will suddenly be activated. This may result in less coupled energy at higher voltages than at lower voltages where the protective device is still inactive. Thus the EUT may prove to be more susceptible to a lower or intermediate voltage than to a higher voltage.

b. Dual Polarity Testing. Both negative and positive pulses are applied.

c. Repetitive Pulses. High voltage pulses can incrementally weaken components with no apparent damage after the initial pulse. Thus for an inverter which survives all voltage increments three pulses are applied at the highest charge voltage level. Repetitive pulses are at least one minute apart.

d. Unpowered Evaluations. When external power is provided to the EUT there is the potential for greater stress to components. Breakdowns due to surges can be exacerbated by the large amount of energy available from either the dc or ac lines. This extra current, supplied by the equipment under test, is referred to as "follow" current. Since the stress is lower in the unpowered EUT case, unpowered evaluations may be completed prior to powered up evaluations.

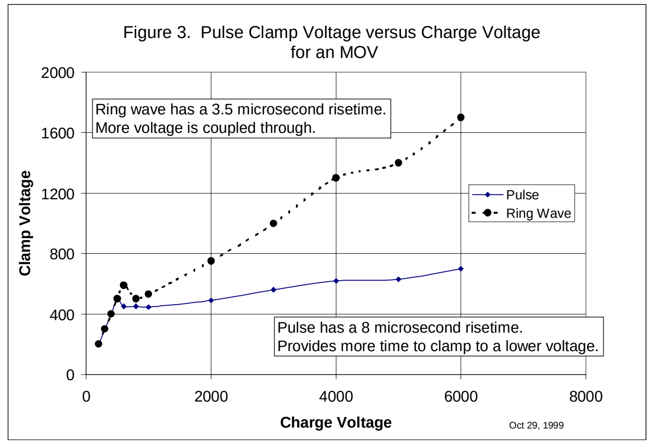
e. Powered Evaluations. Powered evaluations are necessary because of the likelihood of "follow" current and because of the need to evaluate the survivability of anti-islanding features of grid-tied inverters. Because of the possibility of latent damage to these critical circuits, an anti-islanding test should always be conducted after each significant voltage increase in a surge test. Filters are required between the EUT and other power sources to protect the power source and to present a high impedance to the surge.

f. Evaluation of Transfer Functions. A transfer function that defines the current that passes through the protection circuitry is useful for designers. Care must be taken to avoid significantly changing the circuit configuration or damaging instrumentation. This is accomplished by monitoring the signal with a current probe. The monitored wire is wrapped in mylar to prevent arcing and centered in the current probe, to minimize capacitive coupling. The signal from the current probe may be fed to a battery-operated oscilloscope and thus isolated from ground.

The transfer function also provides a means for detecting flashover or breakdown in the applied signal. Initially the signals are applied at low voltage where no possibility of flashover exists. As the charge voltage is increased, the coupled signal envelopes will be identical and will scale in magnitude unless a nonlinear effect occurs. Thus a change in the coupled signal envelope or a failure to scale linearly implies that a nonlinear event has occurred.

3. Evaluations of Surge Mitigation Devices

The evaluations of a typical metal-oxide varistor (MOV) and a silicon spark gap are presented below. Note that the ring wave, which has a faster rise time, rises to a higher voltage prior to being clamped. As the charge voltage is increased a higher amplitude of peak voltage is coupled past the MOV to potentially vulnerable electronics. This particular MOV was pulsed more than 12 times with no obvious degradation.



A Delta Model LA 302-RG was also evaluated. This unit has been used in many PV applications; it is not clear that the users understood its proper application. Delta's description defines the clamping voltage but does not define the initiation voltage. The initiation voltage, the voltage required to start an arc is usually much larger than the clamping voltage. The LA 302RG had no effect at surge voltages up to 6 kV. A physical examination of the arrestor revealed that it is a silicon-filled (sand) spark gap.

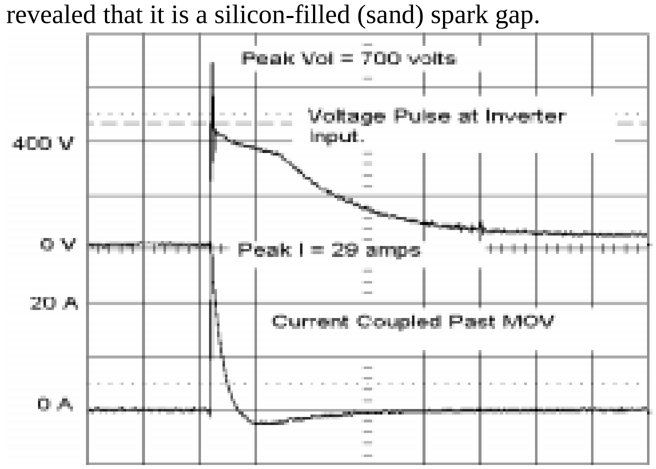


Figure 4. Test Data from the Omnion Inverter

This clamping effect is clearly seen in data from a pulse test of an Omnion inverter that uses an MOV. In Figure 4 the 6000 volt 8 x 50 μ second output of the surge generator is limited to a peak of 700 volts. This is quickly clamped to a voltage of about 400 volts. The current spike (current into the inverter) is limited to 29 amps peak and is of very short duration. The current is measured after the MOV and its shape is affected by other inverter components.

Conclusions

The surge testing of power electronics and surge protection devices at SNL will continue with emphasis on providing practical guidelines for manufactures and users.

References

[1] IEEE Std C62.41 91, IEEE Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits.

[2] IEEE Guide on Surge Testing for Equipment Connected to Low-Voltage AC Power Circuits.